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# SUSCEPTIBILITY OF A PARALLELOGRAM TYPE SKIN FRICTION BALANCE TO ROTATIONAL MOTION

By

R. N. Demers

J. E. Leugers

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Mechanical Instrumentation Group
Experimental Engineering Branch
Aeromechanics Division
Flight Dynamics Directorate
Wright Laboratory
Wright-Patterson Air Force Base, OH 45433-6553

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| ROSARIO N. DEMERS | JOHN E. LEUGERS |

FOR THE COMMANDER

| | |
|---|---|
| DANIEL M. PAROBEK, Tech Mgr<br>Mecnanical Instrumentation Group<br>Aeromechanics Division | DAVID R. SELEGAN, Act Chief<br>Aeromechanics Division<br>Flight Dynamics Directorate |

## FOREWORD

This report was prepared by reserve officer Major Rosario N. Demers and Mr John E. Leugers of the Experimental Engineering Branch, Flight Dynamics Directorate, Wright Laboratory, Aeronautical Systems Division, Wright-Patterson AFB, OH. This effort was conducted under work unit 24041324, "Skin Friction and Heat Transfer Instrumentation."

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# ABSTRACT

The Flight Dynamics Directorate at Wright-Patterson AFB is currently involved in skin friction research in the Mach 3 and Mach 6 High Reynolds Number (HRNF) facilities. The current instrument used to measure the shearing forces is a modified version of the NASA Langley parallelogram type skin friction balance tailored for operation in adverse thermal and dynamic environments. Although the balance has provided excellent results in both the Mach 3 and Mach 6 HRNF facilities, some concerns exists with the data at the very lowest stagnation pressures at Mach 3. At these low pressure (at $P_{0s}$ of 80 psia) the balance and other measuring instruments experience erratic signal outputs. The concern therefore is whether the erratic behavior of the balance is due to tunnel vibration at low stagnation pressures or to aerodynamic conditions within the tunnel. A laboratory test was devised to determine at what frequency and amplitude the balance would experience erratic behavior. This report investigates the vibration test and analysis on the skin friction balance.

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## INTRODUCTION

The Aeromechanics Division at Wright-Patterson Air Force Base has been developing and evaluating direct reading skin friction balance since 1983. The concept of the design discussed in this report is a modified version of the NASA Langley SFB-02 balance. The balance is a direct reading, self-balancing (nulling), parallel-linkage, and control feedback unit. It has been modified to withstand the hostile environments of the Mach 3 and Mach 6 High Reynolds Number facilities. Modifications were made with a variety of major goals in mind which include: small outside diameter and height, and small sensing element size so that highly accurate local skin friction values could be obtained. The balance was also required to be capable of withstanding hot and cold environments, be protected against transient forces, accommodate varying surface roughnesses, and potentials for damping of mechanical and aerodynamic excitation. Although the balance did meet all of its goals, some performance concerns remain during use at low stagnation pressures of the Mach 3 High Reynolds Number Facility.

Erratic signal output was observed of the Skin Friction Balance (SFB) during low Po operating conditions on the Mach 3 tunnel. There are questions concerning the cause of this behavior. The Mach 3 tunnel has a tendency toward higher turbulence levels during low Po conditions since other measuring instruments also behave somewhat erratically. Otherwise the modified SFB has provided excellent results. The concern, therefore, is whether the SFB's erratic output is due to a vibrational mode at these conditions or possibly an

aerodynamic conditions within the tunnel. A laboratory test was devised to determine if the vibration could be the predominant cause of the erratic SFB output.

Prior to this vibration test the following factors were considered:

1. The skin friction balance is designed to allow for only one degree of freedom. All other motions are effectively minimized by using mechanical constraints and symmetrical distribution of mass within the moving elements of the balance. Only forces which are in the allowed direction of sensor head motion affect the output signal. The allowed forces include aerodynamic induced forces tangential to the sensor head surface (skin friction), the restoring force of the linear motor and the effects of torsional accelerations of the entire balance.

2. A linear electrical motor is used within the balance to restore the sensor head to null position. The restoring force produced by this motor is directly proportional to the electrical current. However, the electrical current is limited in magnitude and response. Therefore its capability to correct very large forces is eventually limited.

3. Since the balance consists of a closed loop control system some resonances are expected. However, these can and have generally been damped electronically.

4. Nonrotational vibration tests were conducted on the balance several years ago. These tests confirmed the balance's relative immunity to linear accelerations.

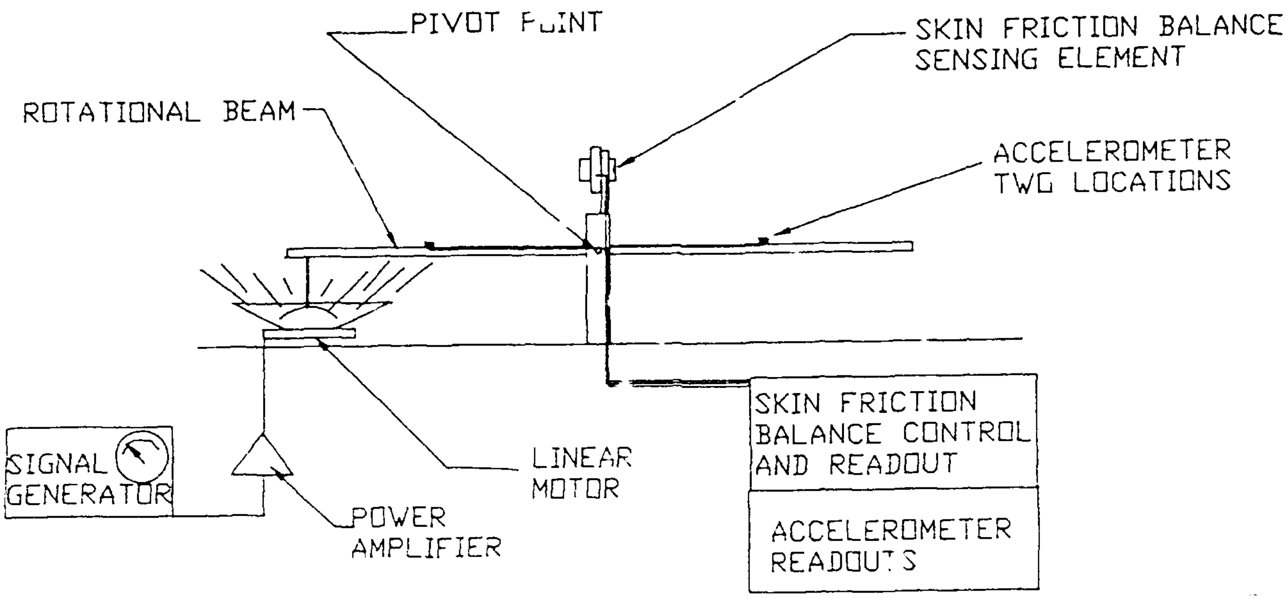
Although the SFB design suggests its susceptibility to torsional motion, no test had ever been conducted to measure its effect. Therefore, emphasis was placed on the construction of a fixture to test the SFB under torsional vibration conditions in the laboratory.

## EXPERIMENTAL SET-UP

The fixture designed and built to test the balance under torsional vibration is illustrated in Figure 1. The motor used to produce the motion is a standard audio speaker to which a linkage was attached from its cone to a rotation beam. The SFB is attached to the beam close to the pivot point so as to minimize linear motion to it. The mounting orientation of the SFB (i.e. the force measuring direction) was made to coincide with the rotating motion of the beam. Two accelerometers were attached 3 inches away on opposing sides of the beam pivot point to provide the acceleration measurements. The exitation to the speaker was provided by a signal generator through a direct couple power amplifier. The SFB control/readout and accelerometer readouts were attached as required to collect the necessary data.

The frequencies and amplitudes selected for the test were varied from 10 to 100 Hz and from 10 to 40 rads/sec$^2$ rms, respectively. The frequencies were measured through a frequency counter whereas the amplitudes were measured through a voltmeter in terms of millivolts rms. The sensitivity of the amplitude measurement was calibrated to 10 rads/sec$^2$ rms. In addition to the configuration described earlier, the SFB orientation was rotated 90$^0$ from the plane of rotational motion and the balance susceptibility was again tested through the same frequency range. The results of this test were not recorded since the balance behaved well, even at amplitudes one order of magnitude higher than those used in the first test configuration.

# TORSIONAL VIBRATION TEST FIXTURE




(FIG. 1)

## TESTING AND RESULTS

As the angular accelerations are increased beyond 10 rads/sec$^2$ rms, there is erratic balance behavior at the lower excitation frequencies. The band of frequencies for which the balance output is erratic increased in proportion to the amplitude. Above 30 rads/sec$^2$ rms the balance output is adversely affected throughout the frequency span. Although there are some resonance effects noted at 13 Hz and at 50 Hz, these effects are minimal in contrast to the overall behavior of the system (refer to Table 1 for data).

SKIN FRICTION BALANCE TORSIONAL VIBRATION TEST

| AMPLITUDE MV rms* | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
|---|---|---|---|---|---|---|---|
| FREQUENCY HZ | BALANCE OUTPUT IN MV (Millivolts) | | | | | | |
| 10 | .089 | .094 | .120 | .176 | .150 | .184 | .220 |
| 11 | .090 | .095 | .142 | | | | |
| 12 | .092 | .105 | .175 | .226 | .238 | .278 | .320 |
| 13 | .091 | .112 | .170 | | | | |
| 14 | .089 | .102 | .144 | | | | |
| 15 | .089 | .099 | .122 | .190 | .285 | .355 | .463 |
| 17 | .086 | .091 | .097 | .125 | .215 | .292 | .376 |
| 19 | .086 | .091 | .093 | .106 | .160 | .201 | .308 |
| 20 | .085 | .089 | .093 | .095 | .150 | .201 | .280 |
| 25 | .085 | .086 | .091 | .092 | .105 | .174 | .217 |
| 30 | ** | ** | .089 | .091 | .093 | .160 | .200 |
| 35 | ** | ** | .089 | .091 | .092 | .119 | .208 |
| 40 | ** | ** | .089 | .092 | .094 | .342 | .419 |
| 50 | ** | ** | .092 | .095 | .232 | .330 | .440 |
| 60 | ** | ** | .093 | .093 | .120 | .500 | .800 |
| 70 | ** | ** | .090 | .093 | .234 | .692 | 1.17 |
| 80 | ** | ** | .088 | .093 | .109 | .542 | 1.02 |
| 90 | ** | ** | .087 | .091 | .202 | .210 | .957 |
| 100 | ** | ** | .086 | .088 | .089 | .090 | .910 |

NOTE: balance zero output was .0875 at beginning of test and .0825 at the end. Zero shift of .005 millivolts.

* 1 Millivolt rms relates to 10 radians/$sec^2$ rms

** Not recorded due to continued low output

TABLE 1

## CONCLUSION

Several conclusions regarding this test can be made. The SFB is susceptible to torsional vibrations coincident with the force measurement direction of the SFB and has a high immunity to other vibration modes. There is, however, a threshold, even in the susceptible mode, for which the balance can be used successfully. This is due to the allowable displacement in which the balance's sensor head can move before exceeding its physical constraints. This displacement is limited to $\pm.005$ inches. Although a linear motor within the skin friction balance is used to restore the sensor head position, the force provided by this motor is exceeded whenever the angular accelerations imposed on the balance exceeds 10 rads/sec$^2$ rms and for which total sensor head displacement exceeds the balances's physical constraints. Since the displacement for a given acceleration is inversely proportional to the square of the frequency, the adverse behavior of the balance is therefore also related to the imposed torsional frequency.

The approach now is to determine the actual vibration conditions of the Mach 3 tunnel. If the thresholds of the torsional vibration conditions are lower than those implicated by Table 1 data then there is a high possibility that the erratic behavior of the SFB is related to aerodynamic conditions within the tunnel and not to the tunnel vibration. Therefore, instrumentation is needed to measure the torsional vibration conditions on the Mach 3 tunnel at low stagnation pressures in order to substantiate the course of the SFB erratic output.

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